Implementation Of A Double Inversion-Recovery Sequence With An Echo-Planar Imaging Readout: Application To Functional Magnetic Resonance Imaging

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Introduction

Functional magnetic resonance imaging (fMRI) is now widely used in clinical and cognitive neurosciences, with echo-planar imaging (EPI) being used to acquire sequential images of a subject while they are performing a task. Interpretation of fMRI data sets typically involves carrying out a statistical analysis at every intracerebral voxel in the image and, because of this, strict corrections must be made for multiple comparisons. The only effects of interest, however, are those that occur in the grey matter, and so the sensitivity to detect brain activation would be improved by restricting the search volume of the analysis to the grey matter only. This could potentially be achieved by using a post-processing segmentation technique, but such a method would be affected by the partial-volume effect and the poor contrast of EPI scans. An alternative approach would be to use a double inversion-recovery (DIR) sequence to image selectively the grey matter at the point of acquisition, and to make use of this information in the fMRI analysis. It must be ensured, though, that the images obtained using the DIR sequence match the distortions that are inherent in the EPI-based fMRI data set. For this reason, a double inversion-recovery sequence with an echo-planar imaging readout has been developed.

Methods

The DIR sequence uses two 180° inversion pulses to null simultaneously the signals from two different tissue types, in this case white matter and cerebrospinal fluid (CSF). It was first introduced by Redpath and Smith (1994)[(1)], in which a spin-echo sequence was used to acquire the images, and it has subsequently been implemented using a fast spin-echo readout[(2)]. The DIR-EPI sequence was generated by adding two inversion pulses to a standard gradient-echo EPI sequence. The imaging parameters required to null the tissues depend not only on the inversion pulses applied but also on the type of readout that is used, as this will have an effect on the evolution of the longitudinal magnetisation. We have derived an equation for the DIR-EPI sequence as, to the best of our knowledge, this is not available in the literature. The longitudinal magnetisation M_A available immediately prior to the 90° excitation pulse is given by

$$M_A = M_0\left[1 - 2\exp\left(-\mathrm{TI}_2/T_1\right) + 2\exp\left(-\left(\mathrm{TI}_1 + \mathrm{TI}_2\right)/T_1\right) - \exp\left(-\mathrm{TR}/T_1\right)\right], \qquad [1]$$

where M_0 is the equilibrium value of the longitudinal magnetisation, T_1 is the longitudinal relaxation time, TI_1 is the time interval between the two 180° inversion pulses, TI_2 is the time interval between the second 180° inversion pulse and the 90° imaging pulse and TR is the repetition time.

Inversion-recovery sequences can use sequential inversion, which is most efficient for short inversion times, or interleaved inversion, which is more appropriate when the inversion time is long[(3)]. Optimised interleaved (OIL) inversion[(2, 3, 4)] minimises the dead time between pulses and data readout and can therefore be very efficient, which is particularly important in this case due to the time required to perform an EPI readout; for this reason, an OIL scheme was used here.

An inversion-recovery EPI sequence was first used to measure the T_1 values of white matter and CSF *in vivo*, by looking for the inversion time that gave maximal suppression of the tissue type in question. Using these results and equation [1], a graphical method[(1, 2)] was used to determine the values for the inversion times TI_1 and TI_2 that would null the signals from both of these tissue types. The acquisition parameters used for a preliminary implementation of the DIR-EPI sequence were thus a repetition time of 4000 ms, an echo time of 20 ms, inversion times of $\mathrm{TI}_1 = 1666.6\,\mathrm{ms}$ and $\mathrm{TI}_2 = 255.5\,\mathrm{ms}$, a slice thickness of 5 mm with a gap of 0.5 mm, a number of excitations of 4, a field of view of 24 cm and a matrix size of 128×128. Images were acquired using an Excite Twinspeed 1.5-T MR system (General Electric Medical Systems, Milwaukee, WI, USA), using the body coil to transmit and an 8-channel phased-array head coil to receive the signal. For comparison, an image was also acquired in the same scanning session using an ordinary EPI sequence, with the same acquisition parameters as above but with no inversion pulses.

Results

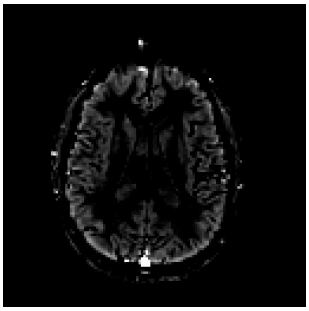

Figure 1(*a*)

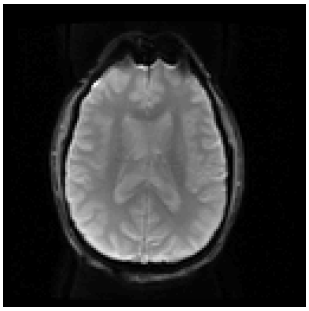

Figure 1(*b*)

Figure 1(*a*) shows a typical image slice obtained using the DIR-EPI sequence, and Figure 1(*b*) shows an image slice of the same region of the anatomy that was acquired using an EPI sequence. It can be seen that the DIR-EPI sequence is successful in imaging the grey matter while achieving satisfactory suppression of the signal from white matter and CSF. A small amount of CSF signal remains in the image, which is probably due to in-flow effects. There is also residual signal from the scalp, and a strong signal from blood in the sagittal sinus; this latter could easily be reduced by the application of flow compensation, which was not used in this case.

Conclusions

A double inversion-recovery sequence with an echo-planar imaging readout has been developed, and it has been shown that it can be used to image selectively grey matter. The resulting image can be inherently distortion-matched with an EPI-based fMRI data set acquired during the same session; it is even possible to acquire a DIR-EPI image using a matrix size that is higher than that used here, and higher than would ever be used for routine functional imaging, while still matching the distortions[(5)]. Furthermore, the use of the OIL scheme keeps the necessary scan time to a minimum, and greatly improves the efficiency of the sequence as compared to the only previous implementation of a DIR-EPI sequence of which we are aware[(6)].

Future developments will include optimisation of the inversion slice thickness so as to minimise in-flow effects. The DIR-EPI image can then be used (possibly with a simple thresholding procedure) to mask fMRI data such that any subsequent analysis would only take into account those voxels that contain grey matter. It is to be expected that such a procedure would result in a significant increase in the sensitivity of the statistical analysis, which would therefore allow more subtle cognitive effects to be detected.

References

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